Study of time dependent properties of concrete on bridges built by the cantilever method

Miguel Munoz (IV)*, Bruno Briseghella*, Miguel Munoz (III)+

Fuzhou University, Fuzhou, China*
The Higher University of San Andrés, La Paz, Bolivia+

Abstract The construction of segmental bridges by the cantilever method is a common construction technique that is applicable to structures with tall piers or where the disposition of conventional superstructure formworks is not viable. In synthesis, the technique consists of building the deck of the bridge by segments with lengths between 3 to 5 meters. This bridge typology requires a step-by-step analysis that considers the evolution of the stage construction in time. The main problem in the analysis of these structures is that the loads are applied to different static schemes of the structure over time. The two type of bridges considered in this research are; a) prestressed concrete and b) composite (steel and concrete) decks. In both cases there is a reduction of the stiffness of the concrete and an increase of the deformations in time. Due to this phenomena there is a redistribution of stresses caused by the dead load that evolves over time, starting from two statically-determined cantilever beams and finishing as a statically-indetermined continuous beam once the construction process is complete and creep, shrinkage and relaxation of steel are finished. The purpose of this work is to analyse a composite deck and a prestressed concrete deck both built by the cantilever method and compare the redistribution of stresses and deformation in time that occur in both structures. The state of the art of time dependent properties in concrete are explained as well as the simplified methods available to quantify these phenomena and the possible structural pathologies that may happen from an incorrect estimation of such effects.

1 Introduction

Concrete has been used for near one hundred years for the construction of bridges and since the first observation of its performance, the time dependent properties of concrete (creep, shrinkage and relaxation) have been difficult to predict with certain accuracy and to understand their complex influence. The first person that detected this phenomenon was Eugène Freyssinet in the construction of his first arch bridges [1]. Since then, engineers and researchers have been aware of the time-dependent behaviour of concrete structures: Glanville, Dischinger, Troxell et al.(1958), L'Hermite et al. (1965), Arutyunian, Powers,Hansen and Mattock (1966),Neville et al.,(1983), Trost, Bazant, etc. Some more recent works about these problems are presented in [2–4]. On this works there are some popular procedures to calculate their order of magnitude and the influence on the response of the structure, however their exact magnitude is still uncertain and the interaction between materials and elements during the construction and service stages by this phenomena results in: additional deflection, cracking, reduction of prestress force and redistribution of internal forces in a sectional level and in an structural level, especially if there is a change on the static scheme, which in turn affect the long-term structural performance. Therefore the time-dependent effects are significant for serviceability limit states under which deflections, stresses and crack widths should be controlled [6–9]. With the improvement of the numerical methods like finite element method is possible to achieve certain accuracy of the phenomenon's related to time-dependent analysis of concrete structures in many step and time by a time integration method [3][10]. The most usual method to do this, is to consider the concrete members represented by frame elements and the tendons modeled as truss elements with nodes with rigid arms to connected them to the beam elements [11][12][13][14][15]. During the construction is usually required an updating of the properties introduced into the model, this technic allow us to get a more similar response of material concrete in the displacements compared to the real deformation on the deck. On the research presented by [16] the deformation in service of the bridges are sometimes very different to the values expected in the calculations. Similar problem in the evaluation of the deformations could be presented during the construction. The paper compares the behaviour of a bridge composed by only prestressed concrete and a bridge built with a composite deck, using as case study a bridge constructed in the Naylon River in Spain. In the research an assessment of the response of the deck was done considering two types of typologies of deck, different construction stages and properties of concrete to verify the stresses and deformations on the deck.

This paper first introduces and compare some formulation to calculate creep, shrinkage and explain the main parameters that conditioned the final magnitude in different codes and related works of time dependent properties of concrete. Then it is presented two approaches to calculate how this strains (shrinkage/relaxation) a loss of stiffness (creep) can be introduced in a structural analysis step by step. Finally a finite element model of the case study is presented and some values of the simulations are presented to have a compressive understanding of the variation and development of the stresses and deformations in time.

2 Time dependent properties of concrete

In the following the time dependent properties of concrete are briefly introduced.

Creep: when concrete is subjected to a sustained stress, creep strain develops gradually with time, creep increases with time at a decreasing rate. In the period immediately after initial loading, creep develops rapidly but the rate of increase slows appreciably in time, most part of this deformation is developed in the first years [3]. Creep deformation depends on many parameters [17][18][19], each code around the world have their own calculation method an usually between them the values are different, on figure 1 a) it is presented the variation on the development and the final value of some of them. The variation is caused mainly due to the different materials and environments in different countries.

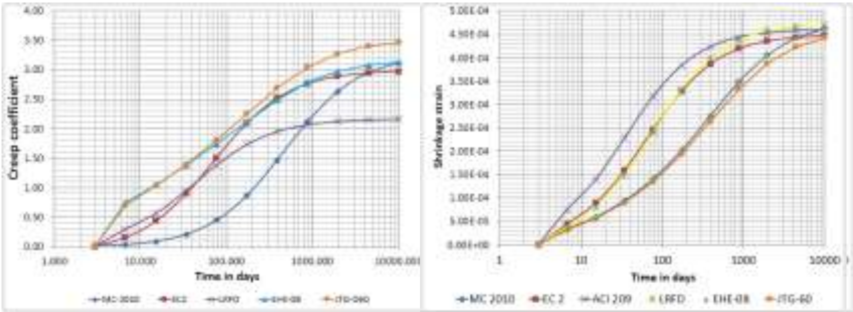

Fig. 1 Left) Creep coefficient and Right) Shrinkage strain in time by various design codes around the world. (MC 2010 Model code, EC2 Eurocode chapter 2, AASHTO LRFD, EHE-08 Spain code 2008, JTG-D62 Chinesse code)

Shrinkage: Is the time dependent strain of concrete in an unloaded and unrestrained specimen at constant temperature. It is important from the outset to distinguish between plastic shrinkage, chemical shrinkage, thermal shrinkage and dry shrinkage [20] in the manner as in creep the codes around the world have their own approaches to calculate the final strain by shrinkage and its evolution figure 1 b).

Temperature: The influence of temperature on the state of stresses and deformations is fundamental on the design of structures [3][10]. For a statically determinate bridge, the seasonal change will not lead to temperature induced stresses but cause deformations. On the other hand in a statically indeterminate structure, the change of temperature, causes large overall expansion and contraction on a bridge depending on the boundary conditions can caused some stressed, the daily fluctuations of temperature, also results in temperature gradients through the depth of the bridge which in turn induce high internal stresses and secondary moments on an indeterminate structure.

3 Stage construction in Bridges

The time dependent properties of concrete are important in state of stresses of structures in general, but their effect becomes more important if the construction of the structure is built in stages. In modern times most of the bridges are built by stages by a mix of prefabricated construction and “cast in situ”. The analysis of the time dependent effects in concrete structures is normally done step-by-step [10] by dividing the time into intervals of time to consider the variation in time of the elasticity modulus, creep and shrinkage of concrete and also the relaxation of prestressed steel.

As it was mentioned before bridge are commonly composed by prefabricated concrete parts (members). This members can be precast or “cast-in situ” and made by concrete of different ages depending on the type of construction (e.g., precast I beam, movable formwork, incremental launched, balanced cantilever, cable-stays, etc). On the construction of a bridge the members are frequently erected, with or without the use of temporary supports, and made continuous with cast-in situ joints or with prestressing force. In all these cases the analysis procedure described below can be used by the application and the superposition of the results using conventional linear computer programs. Only structures that can be idealized as beam or bar elements are considered in this work. At the present times the commercial computer programs can develop a stage construction analysis for plane or space frames, plane or space trusses, or plane grids (e.g., SAP 2000, CSI Bridge, Midas, Sofitk, etc). The analysis made by this software's consider the effects of the sequence of construction and the changes in the statical system and the support conditions during construction but is difficult to have a control of what is the input data and the output data.

In the construction method by segmental balanced-cantilever bridges, the dowels of the deck are assembled in order that the sequence gives a balance of the cantilever side at each pier side and the segments are joined to the previously one by posttensioning. The dowels can be "cast in place" or precast. When the cantilevers sides are one near close to closure and then to each other, they are connected by a "cast-in-place" closure dowel, and a posttensioned by tendons gives the continuity for the structure. Particularly, for cast-in-place segments on a cantilever bridges, the internal forces and the associated deformations are influenced by the different ages of the concrete on the segments, after the continuity is achieved, time dependent deformations cause redistribution of these internal forces and time dependent foundation displacements induce internal forces in the continuous system that are a function of both the rate of the displacements and the rate of creep of concrete. All this parameters are difficult to control in a commercial software so this paper introduces two approaches to calculate this redistribution in a sectional level and the application to the whole structure give to the user a powerful tool to control this effects in the output data.

The construction by the cantilever method with composite structure (concrete steel) have been used from many years in some European countries as Spain [21][22] and other [23]. Actually a mix of prestressed concrete near the piers and a composite section at middle span holds the world record for this typology, the name of the bridge is Shibanpo Bridge, in Chonquing (China). It is expected that the composite solution will have a high redistribution in sectional level but in a structural level the final result is less than in a prestressed concrete bridge [24].

4 Approaches used in a conventional linear software to consider the stage of construction

Creep, shrinkage (concrete) and relaxation (prestressed steel) induces strains between the different material in a section of a bridge, these strain interacts between them with the other materials that compose the members on a structure, by this interaction in the sections a state of stresses is generated that equilibrates this strains an keep the materials together. A procedure to calculate these interaction between materials is presented in [10][20][25], that usually calculated by a simple relationship between the internal forces (axial force and bending moment) and the plane of deformation in a section - axial strain (ε) and curvature (κ)-, the matrix that relate this to parts; internal force and plane of deformation, is composed by the principal geometric properties of the homogeneous section (Area A, first moment of inertia B and second moment of inertia I) (see eq. 1). The assumption of this procedure are:

$$\begin{bmatrix} \Delta\varepsilon_o \\ \Delta\kappa_i \end{bmatrix} = \frac{1}{\overline{E}_{ref}\left[\overline{AI}-\overline{B}^2\right]} \begin{bmatrix} \overline{I} & \overline{B} \\ \overline{B} & \overline{A} \end{bmatrix} * \begin{bmatrix} -\Delta N \\ -\Delta M \end{bmatrix} \quad (1)$$

By this system of equations is possible to calculate the external forces caused by creep, shrinkage and relaxation that are developed in the section see equation (eq. 2), where ΔN and ΔM are axial force and bending moment and Eref is the reference elastic modulus.

$$\begin{pmatrix} \Delta N \\ \Delta M \end{pmatrix} = \begin{pmatrix} \Delta N \\ \Delta M \end{pmatrix}_{flu} + \begin{pmatrix} \Delta N \\ \Delta M \end{pmatrix}_{ret} + \begin{pmatrix} \Delta N \\ \Delta M \end{pmatrix}_{rel} \quad (2)$$

The increments of axial force and bending moment are calculated by equation (eq. 3), (eq. 4) and (eq. 5) for creep, shrinkage and relaxation respectively.

$$\begin{bmatrix} \Delta N \\ \Delta M \end{bmatrix}_{flu} = -\sum_{i=1}^{m} \overline{E_{ci}}(t,t_0)\,\varphi(t,t_0) \begin{bmatrix} A_{ci} & B_{ci} \\ B_{ci} & I_{ci} \end{bmatrix} * \begin{bmatrix} \varepsilon_o(t_o) \\ \kappa_i(t_o) \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \Delta N \\ \Delta M \end{bmatrix}_{ret} = -\sum_{i=1}^{m} \overline{E_c}(\varphi(t,t_0) * \varepsilon_{sh}(t,t_o) * \begin{bmatrix} A_{ci} \\ B_{ci} \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} \Delta N \\ \Delta M \end{bmatrix}_{rel} = \sum_{i=1}^{m} \begin{bmatrix} A_{ps} * \Delta\overline{\sigma}_{pr} \\ B_{ci} * y_{ps} * \Delta\overline{\sigma}_{pr} \end{bmatrix} \quad (5)$$

Where εsh and φ (t,to) are strain by shrinkage and creep in a determinate period of time, the geometrical properties for creep and shrinkage are just related to the concrete part and the properties for relaxation are related to the prestressed steel section. Once the calculation on a sectional level is done the next step is to introduce equivalent forces for this two methods based on the introduction of external forces in the structure [14].

1. Analysis on a sectional level integrated to a matrix system; in a linear software, the structure should be represented by bars with the homogenization of all the subsections that in our case compose the deck and that they are represent by the geometric properties. The functions calculated for creep, shrinkage and relaxation should be also calculated in convenient intervals of time representing the stage of construction of the bridge and also the evolution of them. In each interval of time a corresponding axial force and bending moment calculated from the previous equations cancel the axial strain and bending moment caused by the time dependent properties. This external forces should be applied to the structure as external forces and should be applied to the level of the gravity center of the section in order to modify the stiffness matrix so as to represent the change of stresses by the time dependent properties. The values obtain in equation (eq. 6) and (eq. 7) calculate this effects per each interval of time.

$$\Delta N_i = -A_h * E_h * \Delta\varepsilon_c(t_i) \quad (6)$$

$$\Delta M_i = -I_h * E_h * \Delta\theta_c(t_i) \quad (7)$$

Where ΔNi is the increment of axial force in the interval, ΔMi is the increment of bending moment in the interval, $\Delta\varepsilon_c(t_i)$ is the increment of axial strain in the determinate period, $\Delta\theta_c(t_i)$is the increment of curvature in a determinate period of time. Eh, Ah and Ih are the elastic modulus, area and second moment of inertia of the homogeneous section.

2. Analysis on a structural level taking into account the assumption of plane deformations: With a similar scheme of elements presented before, representing the bars each one of the subsection, is possible to represent the geometry of the subsections for example on the case of a composite; on bar to represent the steel and the second one the concrete and joint them by a link bar with infinite stiffness in the transversal direction. The increment of axial strain (eq. 8) and curvature calculated for the concrete (eq. 9) is only applied to the concrete subsection.

$$\sum_{i}^{j-1} \frac{\Delta N_k}{EA_k}\left[\varphi\left(t_j, t_i\right) - \varphi\left(t_{j-1}, t_i\right)\right] + \Delta\varepsilon_{rkj} = \Delta\varepsilon_{tot}\left(t_j, t_{j-1}\right) \quad (8)$$

$$\sum_{i}^{j-1} \frac{\Delta M_k}{EI_k}\left[\varphi\left(t_j, t_i\right) - \varphi\left(t_{j-1}, t_i\right)\right] = \Delta\kappa_{tot}\left(t_j, t_{j-1}\right) \quad (9)$$

Where $\varphi\left(t_j, t_i\right)$; is the creep coefficient in the interval tj y ti, $\varphi\left(t_{j-1}, t_i\right)$ is the creep coefficient in the previous interval , $\Delta\varepsilon_{rkj}$; is the axial strain the interval tj y ti-1, ΔN_k; is the external axial force that is increased in the previous interval tj y ti-1, ΔM_k;is the increment of bending moment in the interval of time tj y ti-1, $\Delta\varepsilon_{tot}$; is the increment of axial strain in the interval of time tj y ti-1, $\Delta\kappa_{tot}$; is the increment of rotation in the interval of time tj y ti-1, E, Ak y Ik; are the elastic modulus, and first and section order of inertia of the section.

5 Case Study

The case study for this research is a real bridge built over the Nalón River. As a part of the construction to increase the number of traffic lanes on the road AS-17 between Avilés and Puerto de Tarna, in the Riaño-Sama in Asturias (Spain). The design was done by IDEAM and the construction developed by UTE Riaño-Sama II. The bridge has a total length of 165 meters divided in three span (Fig 2); the later spans composed by prestressed spans of 27.5 meters and the central span 110 meters composed by a prestressed part near the intermediate supports and composite section at the middle section. The composite section is composed by two twin girders closing the section by a double concrete slabs at the top and bottom of the section given a “strict-box” girder Fig 3.D, which gives an innovative solution on the development of the double composite. The concept of the solution of the bridge relies on the use of a heavy deck near the abutment and the intermediate supports and a composite section at the middle of the bridge in order to equilibrate the distribution of internal forces in the deck. For a research propose the stage construction of the deck was also developed for full prestressed deck so as to compare the redistribution of the internal forces, the displacements and the reactions obtain from both solutions.

Fig. 2 Longitudinal view of the bridge on the Naylon River, picture took from [26].

Five models were prepared in order to have a comprehensive analysis on the effect of the time dependent properties of concrete in the deformations and stresses in time. The CSM1 represents a composite solution similar to the real bridge, 18 stages in the numerical model were considerd, 13 of them for the construction and 5 to verify the redistribution of stresses by the change on the static scheme in time until 10000 days. The properties of the concrete are presented on table 1 and the effect of the time dependent of concrete properties were calculated by the CEB-FIp 90 [27]. CM1 corresponds to a full prestressed concrete bridge built symmetric and constructed by 13 stages, 5 stages after the construction were also consider to study the evolution of the deformations in the concrete until 10000 days after the closure. CM2 consider an asymmetric construction, first the left part and then right side. 24 stages were considers for the construction and 5 after that. CM3 considers a symmetric construction considering the construction loads and the prestressed during the cantilever stage and the continuity prestressed, the same 5 stages to control the development were also consider. CM4 is similar to case CM3 but considering a lower elastic modulus of concrete and more creep. In figure 3 there are some drawings of the principal cross sections of the deck for both solutions.

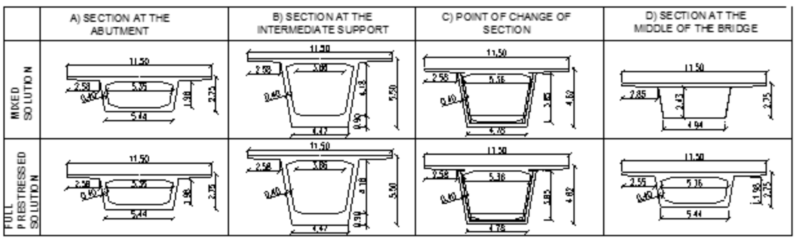

Fig. 3 Principal sections for the two solutions.

Material		
Concrete	***Value***	***Units***
Elastic modulus	32000	[Mpa]
Characteristic strength of concrete.	45	[Mpa]
Weight of concrete	25	[KN/m3]
Cement type Coefficient	0.25	
Relative humidity	60	%
Basic shrinkage coefficient	5	

Table 1.- Concrete properties consider to calculated the evolution of creep and Shrinkage by MC-90.

On model CSM1 there is a redistribution of stresses between the middle span and the intermediate support, but is not so high as in the cases made only by concrete (less than 20%), the reason is that there is less concrete in the composite section so the loss of stiffness in time is also less (fig 4), moreover steel gets some stresses in time because concrete loss it and there is also an effect caused by shrinkage that put the concrete in tension and steel in compression.

In figure 5 is presented the values of the bending moment for the models CM1, 2 and 3. In all cases the bending moment at middle span tends to increase in time and reduce at the intermediate support. The final value on cases CM1 and CM3 are similar to the values obtained as if the bridge was built by a formwork, 80% less in the case of CM1 and 70% in the case of CM3. In case CM2 there is an asymmetric shape on the diagram of bending moment because at the time of closure of the bridges both sides have not the same age on their concretes. The side with a more mature concrete after the closure gets more bending moment than before and at middle span the value also increase. The prestressing, by the hyper static effect on the continuity, applied at the bottom of the slab reduce the effect of the redistribution and equilibrate the bending moment in the structure. The redistribution in all cases is caused by the increment of the deformation of the concrete by creep, during the closure of the cantilever sides of the bridge the slope of the bridges can change by the weight of the deck and “loss of stiffness” by creep, once the closure of the bridge is made, does not allow the slopes increase independently because of the fixity by the closing segment that complete the deck, so an internal force of a compatibility (bending moment) appears at the middle of the deck in order to keep the magnitude of the slope in each side before the closure. As a result a reduction on the stresses on the intermediate support is reach and an increment of the bending moment at the middle span. Due to the redistribution on the internal forces induced by the change of the static scheme, there is also a reduction on the reaction at the abutment and intermediate supports.

Comparing the variation of bending moment between CM3 and CM4 the variation on the final value of the bending moment at middle span and at the supports is around 15% with more increment in CM4. The reason is the lower elastic modulus, see (table 2), on the other hand on the case of vertical deformation, the influence of the elastic modulus is more important (table 3), were the deformation is almost two times even if the difference between the elastic modulus is just 33% less. In the work developed by Bazant et. Al [16], there is an evaluation of the deformation of more 56 bridges built by this method around the world, and it shows that the deformation of creep is larger than a value of 1/800 for most part of them, the true is that codes and recommendation assumed that creep will end around the 10000 year of maturity of concrete but the statistics data shows something different.

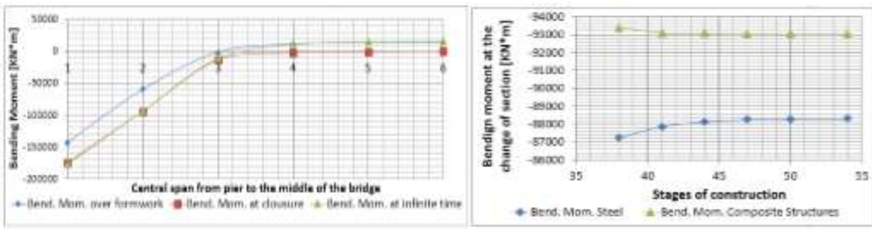

Fig.4 Comparison of bending moments (CSM 1) between the time of closure and the infinite time if built by formwork (Top), variation of the bending moment between composite section and just steel section (Bottom).

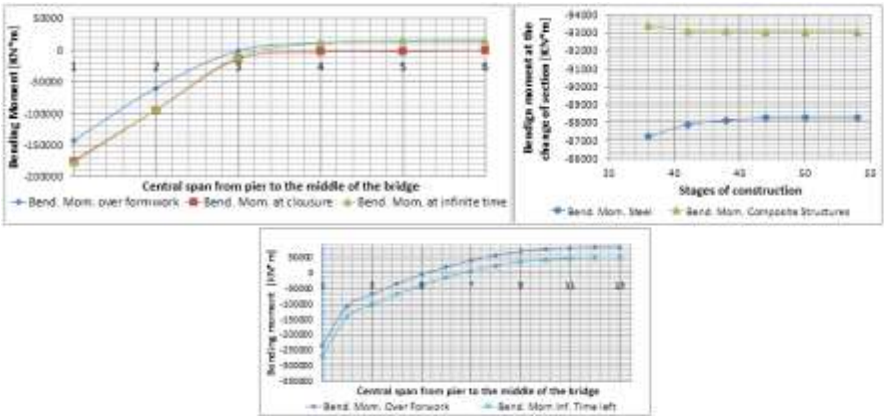

Fig. 5 Bending moment diagram at middles span (top-CM1), (middle-CM2) and (bottom-CM3).

Etapa	Momentos [Mpa] E=22400			Momentos [MPa] E=32000			% of Vararíation		
	Pier	Chan. Secc	Mid. Span	Pier	Chan. Secc	Mid. Span	Pier	Chan. Secc	Mid. Span
Closuse Dow	-334912	-202709		-335004	-202824		0.0275	0.0567	
Cont. Pres	-317687	-190192	855	-318704	-191232	-199	0.3191	0.5438	123.2749
Inf. Time	-260480	-132958	58104	-269034	-141549	49493	3.1795	6.0693	14.8200

Table 2.- Comparison of bending moments obtain by different elastic modulus.

Def. middle span	Def. M3	Def. M4	Var. Def.
	[mm]	[mm]	%
Closuse Dow	-62.90	-67.40	6.68
Cont. Pres	1.50	11.25	86.67
Inf. Time	-117.31	-227.01	48.32

Table 3.- Comparison of the deformation obtain on model CM3 and 4 at different stages.

6 Conclusions

A review of the time dependent properties calculation in the construction of cantilever bridge and how to implement it is presented in this work.

The input data introduced in the numerical model, as e.g (elastic modulus, evolution of creep and shrinkage) give different results on the deformation and the resulting state of stresses. An update of this parameters can be developed during the construction of deck by the continuous level of control in each stage, is possible to obtain an elastic modules and the evolution of the creep doing the inverse procedure presented before, giving the opportunity to develop a simulation of the time dependent properties in real structures in order to improve the methods obtain in the lab test.

The results show that in a composite construction the variation of the deformations on redistribution of stresses are not so high as in the case of a full concrete bridge. The properties for the materials consider in the model and the sequence of the stage of construction are key parameters during the modeling.

Acknowledgments The work was supported by the College of Civil Engineering, Fuzhou University and the Sustainable and Innovative Bridge Engineering Research Center (SIBERC)

References

[1] Pierre Xercavins, Daniel Demarthe, and Ken Shushkewich Eugene Freyssinet – his incredible journey to invent and revolutionize prestressed concrete construction 3rd fib International Congress - 2010

[2] Bažant ZP. Prediction of concrete creep and shrinkage: past, present and future. Nucl Eng Des 2001;203(1):27–38.

[3] Gilbert IR. Time effects in concrete structures. New York: Elsevier; 1988.

[4] Yang IH. Uncertainty and sensitivity analysis of time-dependent effects in concrete structures. Eng Struct 2007;29(7):1366–74.

[5] Marí AR, Bairán JM, Duarte N. Long-term deflections in cracked reinforced concrete flexural members. Eng Struct 2010;32(3):829–42.

[6] Ariyawardena N. Prestressed concrete with internal or external tendons: behavior and analysis. Ph.D. thesis. Calgary (Alberta): University of Calgary; 2000.

[7] Benboudjema F, Meftah F, Torrenti JM. Interaction between drying, shrinkage, creep and cracking phenomena in concrete. Eng Struct 2005;27(2): 239–250.

[8] Yang IH. Prediction of time-dependent effects in concrete structures using early measurement data. Eng Struct 2007;29(10):2701–10.

[9] Malm R, Sundquist H. Time-dependent analyses of segmentally constructed balanced cantilever bridges. Eng Struct 2010;32(4):1038–45.

[10] Ghali A, Favre R, Elbadry M. Concrete structures: stresses and deformations. 3rd ed. London: Spon Press; 2002.

[11] Aalami BO. Time-dependent analysis of concrete structures. Progr Struct Eng Mater 1998;1(4):384–91.

[12] Ariyawardena N, Ghali A. Prestressing with unbonded internal or external tendon: analysis and computer model. J Struct Eng 2002;128(12):1493–501.

[13] ElbadryMM, Ghali A. Analysis of time-dependent effects in concrete structures using conventional linear computer programs. Canad J Civ Eng 2001;28(2): 190–200.

[14] Manterola J. puentes. apuntes para su diseño, cálculo y construcción Coleccion Ingniera de Canales Caminos Puertos 2006

[15] Au FTK, Liu CH, Lee PKK. Creep and shrinkage analysis of reinforced concrete frames by history-adjusted and shrinkage-adjusted elasticity moduli. Struct Des Tall Special Build 2009;18:13–35.

[16] Zdeneˇk P. Bažant, Mija H. Hubler, and Qiang Yu, Excessive Creep Deflections: An Awakening Data from numerous long-span prestressed segmental box girders show alarming trend, Concrete international Aug. 2011

[17] ACI Committee 209 (2008). Guide for modeling and calculating shrinkage and creep in hardened concrete (ACI 209.2R-8). American concrete, Fanaington Hills Mchigan.

[18] Bazant, Z.P and Wittmann, F.H. (eds) 1983. Creep and shrinkage in concrete structures. Jhon Wiley and Sons Ltd.

[19] Neville, A.M. Dilger, W. H and Brooks j.j., (1983) Creep of plain and structural concrete construction Press (Longman Group Ltd).

[20] Gilbert R., I and Ranzi G.. Time-dependent behavior of concrete structures. New York: Spon Press; 2011.

[21] Martinez J., Millanes F., Fernandez J.A, Dos ejemplos de grandes puentes mixtos pretensados en Tortosa y Valencia, hormigón y acero Nº 179, pp. 89-100 (1991)

[22] Millanes F., Ortega M., and Pascual J., El Viaducto sobre el Río Nalón, un puente mixto de carretera con un vano principal de 110 m de luz, Hormigón y Acero Nº 254, pp. 29-42 (2009)

[23] Setra., Steel concrete composite Bridges (2000)

[24] Munoz M, Redistribución de esfuerzos en puentes construidos por Voladizos sucesivos, E.T.C.C.P-UPM Master Tesis Madrid 2011

[25] Iglesias C., Proyecto y calculo de estructuras de Hormigon y Acero, Sintesis editorial Madrid 2013

[26] Millanes F., Ortega M., and Pascual J., El Viaducto sobre el Río Nalón, un puente mixto de carretera con un vano principal de 110 m de luz, Hormigón y Acero Nº 254, pp. 29-42 (2009)

[27] The International Federation for Structural Concrete - FIP, MC-90, CEB-FIP "Design Code" Thomas Thelford (1993)